

# Improving the Quality of Non-Holonomic Motion by Hybridizing C-PRM Paths

Itamar Berger<sup>\*†</sup>, Bosmat Eldar<sup>\*†</sup>, Gal Zohar<sup>\*†</sup>, Barak Raveh<sup>\*†§</sup> and Dan Halperin<sup>\*§</sup>

<sup>\*</sup>School of Computer Science, Tel-Aviv University, Tel-Aviv, Israel

<sup>†</sup>Department of Microbiology and Molecular Genetics, The Hebrew University, Jerusalem, Israel

<sup>‡</sup>I.B., B.E. and G.Z. contributed equally to this work

<sup>§</sup>Email: barak,danha@post.tau.ac.il

## I. INTRODUCTION

Sampling-based motion planners are an effective means for generating collision-free motion paths. However, the quality of these motion paths, with respect to different quality measures such as path length, clearance, smoothness or energy, is often notoriously low. This problem is accentuated in the case of non-holonomic sampling-based motion planning, in which the space of feasible motion trajectories is restricted. In this study, we combine the C-PRM algorithm by Song and Amato [1] with our recently introduced path-hybridization approach [2], for creating high quality non-holonomic motion paths, with combinations of several different quality measures such as path length, smoothness or clearance, as well as the number of reverse car motions. Our implementation includes a variety of code optimizations that result in nearly real-time performance, and which we believe can be extended with further optimizations to a real-time tool for the planning of high-quality car-like motion.

### A. C-PRM

The original C-PRM algorithm for planning car-like motion [1] starts by building an initial *control roadmap*, a probabilistic roadmap devoid of any non-holonomic constraints, in order to capture the coarse connectivity of the free space. It then builds the *approximate roadmap* by converting groups of three nearby points to a valid car path made of straight line segments and arcs that connect between midpoints of edges in the control roadmap (Fig. 1). The C-PRM algorithm takes a lazy approach in which collision checks and final refinements are conducted at query time. Song and Amato showed that the C-PRM algorithm is effective in generating car-like motion paths. Here, we put a special emphasis on improving the quality of these paths.

### B. Path Hybridization for Improving Path Quality

We have recently introduced the path-hybridization approach [2], [3], in which an arbitrary number of input motion paths are hybridized to an output path of superior quality, for a range of path-quality criteria. The approach is based on the observation that the quality of certain sub-paths within

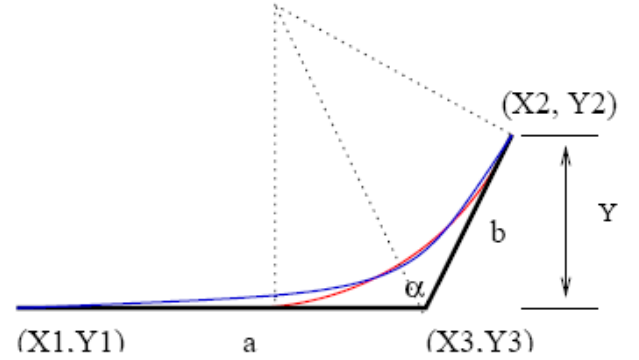


Fig. 1. Moving from the *control roadmap* (devoid of non-holonomic constraints) to the *approximate roadmap* in the C-PRM algorithm for car-like motion planning. Figure is taken from Fig. 2 in Song and Amato [1].

each solution may be higher than the quality of the entire path. Specifically, we run an arbitrary motion planner  $k$  times (typically  $k=5-6$ ), resulting in  $k$  intermediate solution paths to the motion planning query. From the union of all the edges and vertices in the intermediate paths we create a single weighted graph, with edge weights set according to the desired quality criterion. We then try to merge the intermediate paths into a single high-quality path, by connecting nodes from different paths with the local planner, and giving the appropriate weights to the new edges. Dijkstra's algorithm is used to find the highest-quality path in the resulting Hybridization-Graph (H-Graph).

## II. C-PRM WITH PATH HYBRIDIZATION

While the path hybridization approach has been successfully tested over a range of holonomic motion planning problems with many degrees of freedom [2], [3], its application to non-holonomic motion planning is not trivial. In particular, whereas it is easy to connect two nearby configurations in the case of holonomic motion (for example, by linear interpolation between the two configurations), it is not possible to simply interpolate between two states of non-holonomic motion planning, due to the restriction on the set of possible paths. However, we observed that we can simply reverse engineer the original approach taken by C-PRM for car-like motion

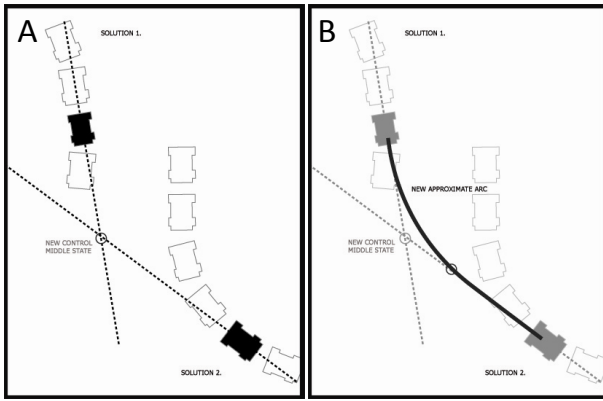


Fig. 2. Connecting two car states by “reverse engineering” of the original C-PRM algorithm. **A** - Finding the intersection point between two car states. **B** - connecting the two states by an arc.

planning, and go from the approximate roadmap (that is made of arcs and line segments) to the control roadmap (the coarse roadmap that does not include non-holonomic constraints), instead of working the other way around (Fig. 2). This allowed us to use the path-hybridization approach in a non-holonomic setting, to generate car-like motion paths of high quality (for example, see Fig. 3).

#### A. Implementation

We have implemented the C-PRM algorithm and C-PRM with path hybridization within the framework of the OOPSMP motion planning package [4]. Our implementation supports the combination of a wide range of path quality criteria (length, smoothness, clearance, as well as the number of reverse car motions). We also include a variety of code optimizations, and our experiments indicate close to real-time performance, which we believe could be even further improved by further reasonable efforts. In Fig. 3 we include an illustrative example of motion planning for a car-like vehicle using our implementation of both the original C-PRM algorithm for car-like motion planning, and the C-PRM algorithm combined with path hybridization. As noted in Raveh *et al.* [2], path hybridization incurs an additional running time cost due to the need for multiple runs of the C-PRM algorithm, but yields motion paths of superior quality, with large flexibility in terms of the quality criteria applied. Further details and a movie are included in <http://acg.cs.tau.ac.il/courses/workshop/spring-2009/final-projects/non-holonomic-motion-planner-project>.

### III. CONCLUSIONS

The problem of finding high-quality motion paths is of prime importance. Due to the constrained nature of non-holonomic motion, it is more difficult to plan high-quality non-holonomic motion paths than holonomic ones. We have designed and implemented the first application of the path hybridization approach to non-holonomic motion planning in the rather simple setting of car-like motion, showing promising results. In order to hybridize non-holonomic paths, we had to develop a non-holonomic local planner to connect

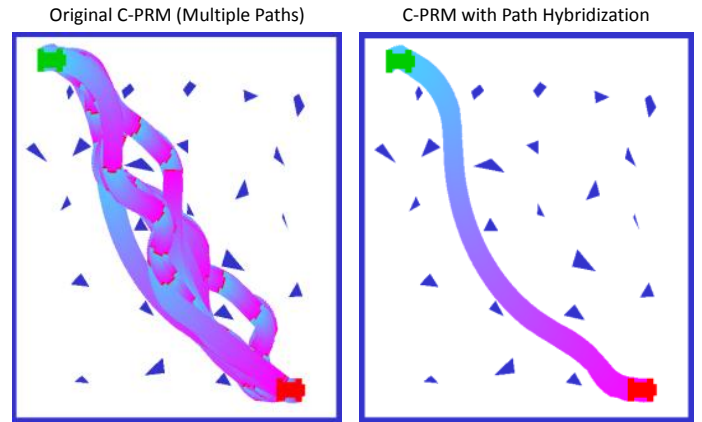


Fig. 3. Experimental results of running C-PRM with Path Hybridization. The left panel shows an overlay of six different motion paths that were generated by the original C-PRM algorithm. The right panel shows the hybridization of these paths by the path hybridization algorithm to obtain a shorter path (as described in the text).

nearby states. Developing similar local planners for other non-holonomic vehicles would allow the extension of the path hybridization approach for a wide range of non-holonomic problems.

#### REFERENCES

- [1] G. Song and N. M. Amato, “Randomized motion planning for car-like robots with c-prm,” in *IEEE Int. Conf. on Intelligent Robots and Systems*, 2001, pp. 37–42.
- [2] B. Raveh, A. Enosh, and D. Halperin, “A little more, a lot better: Improving path quality by a simple path merging algorithm,” *IEEE Transactions on Robotics*, to appear.
- [3] A. Enosh, B. Raveh, O. Furman-Schueler, D. Halperin, and N. Ben-Tal, “Generation, comparison and merging of pathways between protein conformations: Gating in k-channels,” *Biophysical Journal*, vol. 95, no. 8, pp. 3850–3860, 2008.
- [4] E. Plaku, K. E. Bekris, and L. E. Kavraki, “OOPS for motion planning: An online open-source programming system,” in *ICRA 07*, 2007, pp. 3711–3716.